AERODYNAMIC EVALUATION OF THE EXTERNAL FLOW OVER PICKUP TRUCKS

Eduarda Kelly Mascia*, Odenir de Almeida*
***Experimental Aerodynamics Research Center – CPAERO, Universidade Federal de Uberlândia, Faculdade de Engenharia Mecânica, Uberlândia, Brazil**

Keywords: CFD, OpenFOAM, RANS, k-ω SST, pickup.

Abstract

The computational analysis of the external flow over commercial vehicles is increasingly important in the automotive industry since it provides consistent and reliable results which enable significant improvements in new products. In this context this work proposes an aerodynamic evaluation by numerical modeling of the external flow over pickup-trucks. As a tool in engineering it is proposed the use of an open-source code OpenFOAM for the qualitative and quantitative analysis of the flow over the Ahmed body, as validation, and more realistic pickup models. Different meshes and numerical methods were evaluated by employing RANS (Reynolds Averaged Navier-Stokes) through different turbulence modeling. The results were compared to experimental measurements and literature data to validate the numerical approach to be applied in future aerodynamics analyses of such kind of vehicles.

1 Introduction

The high costs associated with conducting experiments in wind tunnels or on the road to analyze the flow around vehicles made the automotive industry to look at new resources to obtain reliable results which allow the modification in products and make them more competitive in the market.

In this context, new alternatives have appeared for the analysis of vehicles by means of CFD (Computational Fluid Dynamics), among them free-license software, such as OpenFOAM, an easy programming operating system that allows aerodynamic simulations with different models of turbulence.

In relation to the use of OpenFOAM software, Nebenfuhr (2010) has presented a comparison between the utilization of this software and the Ansys-Fluent® in the prediction of the flow around vehicles, obtaining a good approximation between the results obtained in the two software, nevertheless noting a strong dependence on the results of OpenFOAM with respect to mesh resolution. Furthermore, Nebenfuhr (2010) proved that Fluent® was capable to simulate meshes with low quality, whereas the same configuration and mesh was diverging in OpenFOAM.

Lewis, Mosedale and Annetts (2009) presented in their work a drag coefficient reduction around 1% by an optimization process using RANS data in OpenFOAM software. In addition, the work exposed that the DES (Detached Eddy Simulation) approach resulted a 500% increase in computing time over the RANS method.

The use of different software for the analysis of the flow around cars, more specifically of the Ahmed body with slope of 25º at the rear, was analyzed by Bordei and Popescu (2011). They have shown that OpenFOAM presented the best cost to quality relation, whose value of drag coefficient obtained has an error around 15.26% compared to the value from the literature (Hucho, 1998).

Regarding experimental tests with pickup trucks, some data are available in literature such as the works of Al-Garni and Bernal (2010), and more recently Almeida (2017). In this last work, the authors were able to generate a new pickup geometry for testing in low-speed wind tunnel. A baseline pickup with flat surfaces was created and a second model was employed by smoothing or filleting the sharp-edges. In their approach, they presented a reduction of the drag coefficient of approximately 30% for the geometry of a pickup with smooth surface. The influence of this modification will also be analyzed by means of computational approach in the present work.

This work therefore aims a validation of OpenFOAM for two different turbulence models by means of applying the Reynolds Averaged Navier-Stokes (RANS) in association with the k-ω SST (Shear-Stress-Transport) and Spalart-Allmaras (AS). Initially an approach-validation was performed using the Ahmed body (Ahmed (1984)), with results obtained by experimental studies of Lienhart (2002). The final computational tests were carried out with the two pickup-truck's geometries from the work of Almeida (2017).

2 Research steps

2.1 Computational Procedure

Initially, the problems were solved with RANS modeling, specifically the k–ω SST turbulence model. The RANS (Reynolds Averaged Navier-Stokes) equations in conservation form for an incompressible fluid are presented in Equations (1) and (2).

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

$$\rho\frac{\partial U_i}{\partial t} + \rho\frac{\partial}{\partial x_j}\left(U_iU_j\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2\mu S_{ij} - \rho\overline{u_i'u_j'}\right) \tag{2}$$

where S_{ij} is the mean strain-rate tensor showed in Equation (3):

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \tag{3}$$

In the RANS approach, the k–ω SST turbulence model was used based on literature data and performance of the model with separated flows. This modeling is a well-known two-equation turbulence approach. The turbulence kinetic energy, *k*, is shown in Equation (4) and the Eddy viscosity is defined in Equation (5).

$$\rho\frac{\partial k}{\partial t} = \tau_{ij}\frac{\partial u_i}{\partial x_j} - \beta^*\rho k\omega + \frac{\partial}{\partial x_j}\left[\left(\nu + \sigma_k\mu_T\right)\frac{\partial k}{\partial x_j}\right] \tag{4}$$

$$\upsilon_t = \frac{a_1 k}{\max(a_1\omega, \Omega F_2)} \tag{5}$$

The specific turbulent kinetic energy dissipation rate, w, is defined in Equation (6).

$$\rho\frac{\partial \omega}{\partial t} = \frac{\Upsilon}{\upsilon_t}\tau_{ij}\frac{\partial u_i}{\partial x_j} - \beta^*\rho\omega^2 + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_k\mu_T\right)\frac{\partial \omega}{\partial x_j}\right] + 2(1 - F_1)\rho\sigma_{\omega^2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \tag{6}$$

Where

$$F_2 = \tanh\left[\left[max\left(\frac{2\sqrt{k}}{\beta\omega y}, \frac{500\nu}{y^2\omega}\right)\right]^2\right]$$

$$F_1 = \tanh\left\{\left\{min\left[max\left(2\frac{\sqrt{k}}{0.09\omega y}, \frac{500\nu}{y^2\omega}\right), \frac{4\rho\sigma_{\omega 2}k}{CD_{k\omega}y^2}\right]\right\}^4\right\}$$

$$CD_{k\omega} = max\left(2\rho\sigma_{\omega^2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}, 10^{-20}\right)$$

$$\tau_{ij} = \mu_T\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right)$$

$$\Upsilon_1 = \frac{\beta_1}{\beta^*} - \frac{\sigma_{\omega 1}k^2}{\sqrt{\beta^*}}$$

$$\phi = F_1\phi_1 + (1 - F_1)\phi_2$$

The coefficients of the k–ω SST turbulence model are: $\sigma_{k1} = 0.83$, $\sigma_{\omega 1} = 0.5$, $\beta_1 = 0.0750$, $a_1 = 0.31$, $\beta^* = 0.09$,$k = 0.41$, $\sigma_{k2} = 1.0$, $\sigma_{\omega 2} = 0.856$ and $\beta_2 = 0.0828$.

Also, as a second modeling, the flow fields were solved with the Sparlat Allmaras (SA) turbulence model. The SA model is a one equation turbulence model derived by Spalart and Allmaras (1992) and have shown important results for automotive industry in certain class of problems. The Reynolds tensor is presented in Equation (7).

$$\tau_{ij} = 2\nu_T S_{ij} \tag{7}$$

Being:

$$\upsilon_t = \tilde{\upsilon} f_{\upsilon 1}, \qquad f_{\upsilon 1} = \frac{\chi^3}{\chi^3 + c_{\upsilon 1}^3}, \qquad \chi \equiv \frac{\tilde{\upsilon}}{\upsilon}$$

The transport equation is showed in Equation (8).

$$\frac{D\tilde{\upsilon}}{Dt} = c_{b1}(1 - f_{t2})\tilde{S}\tilde{\upsilon} - \left(c_{\omega 1} f_{\omega} - \frac{c_{b1}}{k^2} f_{t2}\right)\left[\frac{\tilde{\upsilon}}{d}\right]^2 + f_{t1}(\Delta u)^2 + \frac{1}{\sigma}\left[\nabla \cdot \left((\upsilon + \tilde{\upsilon})\nabla\tilde{\upsilon}\right) + c_{b2}(\nabla\tilde{\upsilon})^2\right] \quad (8)$$

Where

$$\tilde{S} \equiv S + \frac{\tilde{\upsilon}}{d^2 k^2}\left(1 - \frac{\chi}{1 + \chi f_{\upsilon 1}}\right)$$

$$f_{\omega} = \left[\left[min\left(\frac{\tilde{\upsilon}}{\tilde{S} d^2 k^2}, r_{lim}\right)\right] + c_{\omega 2}(r^6 - r)\right] \cdot \left[\frac{1 + c_{\omega 3}^6}{g^6 + c_{\omega 3}^6}\right]^{\frac{1}{6}}$$

$$c_{\omega 1} = \frac{c_{b1}}{k^2} + \frac{(1 + c_{b2})}{\sigma}$$

$$f_{t1} = c_{t1} min\left(0.1, \frac{\Delta u}{\omega_t \Delta x}\right) exp\left(-c_{t2}\frac{\omega_t}{\Delta u^2}\left[d^2 + \left[min\left(0.1, \frac{\Delta u}{\omega_t \Delta x}\right)\right]^2 d_t^2\right]\right) \quad (9)$$

$$f_{t2} = c_{t3} \exp(-c_{t4}\chi^2)$$

The coefficients of the Spalart-Allmaras turbulence model are: $c_{b1} = 0.1355$, $\sigma = 2/3$, $c_{b2} = 0.622$, $k = 0.41$, $c_{\omega 2} = 0.3$, $c_{\omega 3} = 0.2$, $c_{\upsilon 1} = 7.1$, $c_{t1} = 1$, $c_{t2} = 2$, $c_{t3} = 1.2$, $c_{t4} = 0.5$ and $r_{lim} = 10$.

2.2 Validation

The validation was performed from the data of the Ahmed body and pickup models presented in the literature. First, the Ahmed body's results used to make the validation are found in ERCOFTAC (2002) database, that contains information on the velocity profiles in z-direction at various x-positions on the y = 0 m plane.

For the evaluation of Ahmed body, a 2.3 million elements mesh was used. The computational domain and the mesh used in Ahmed body are present in Fig. 1 and Fig. 2, respectively.

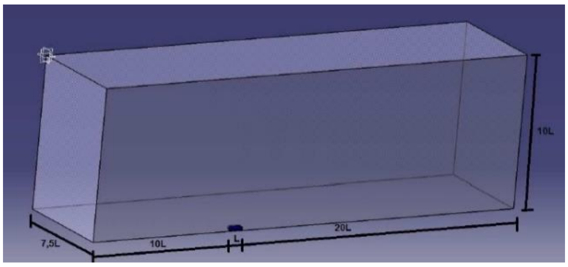


Fig. 1. Computational domain of Ahmed body.

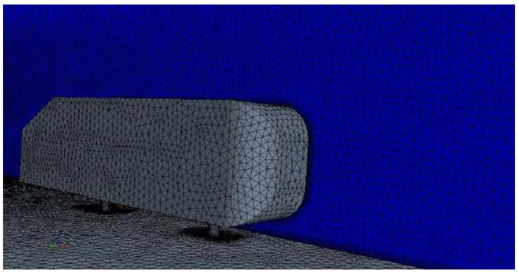


Fig. 2. Mesh of Ahmed body.

In addition, it was performed the analysis about the influence of the mesh resolution on the computational results obtained by OpenFOAM software. For this, two meshes were considered, the first with about 4.8 million elements and the second with approximately 17 million elements. Fig. 3 shows the mesh displayed in the symmetry plane to the first configuration. Fig. 4 shows the mesh in the symmetry plane to the second configuration.

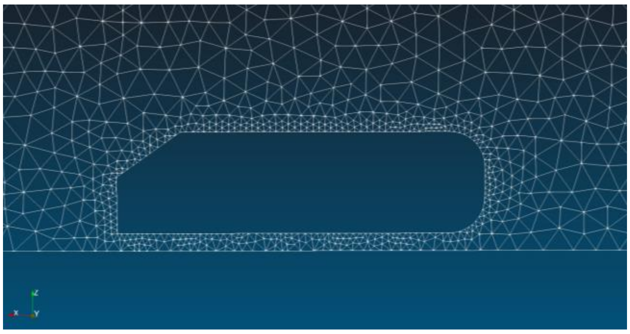


Fig. 3. Baseline mesh on symmetry plane.

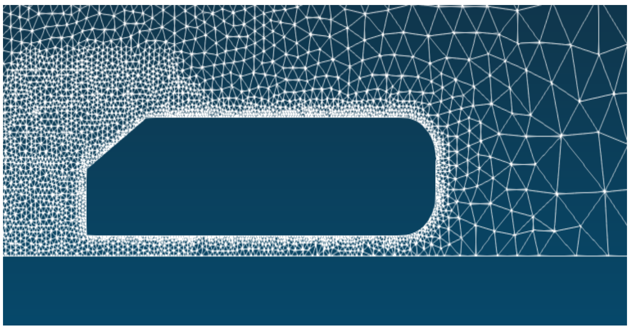


Fig. 4. Refined mesh on symmetry plane.

The Pickup model obtained on the literature contains data about the drag coefficient (c_D) and velocity profiles for two different models, that are used to compare the results obtained in this search. Those data are found in Silva-Pinto (2016). The configurations used in this work are present in Fig. 5.

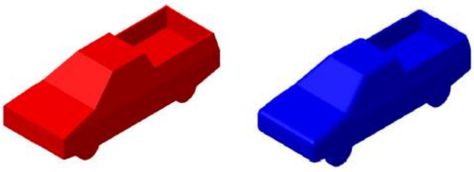


Fig. 5. Pickup baseline (left) and rounded (right) (Silva-Pinto, 2016).

For the baseline-configuration, a 9.86 million elements mesh was used, and for the rounded-configuration, a 9.45 million elements mesh was used. The original meshes created to discretize the baseline and rounded models are present in Fig. 6 and Fig. 7, respectively.

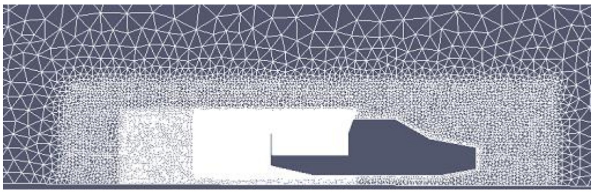


Fig. 6. Baseline model-mesh on symmetry plane.

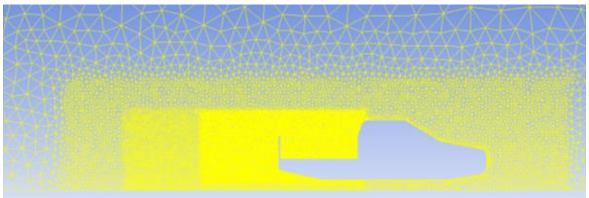


Fig. 7 Rounded model-mesh on symmetry plane.

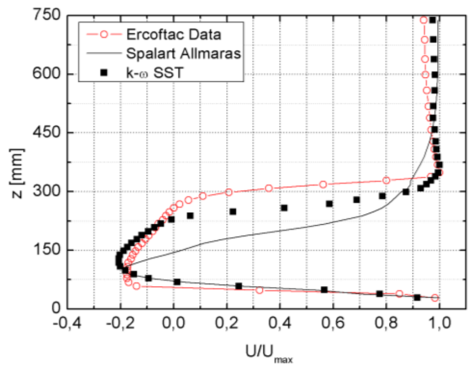
The analyses presented in this work considered that the ground and the bodies surfaces are walls, with no-slip condition, a symmetry plane which splits the model in the middle (half-model simulation), the side field and the upper field are also symmetry condition emulating a far field, the inlet was imposed as velocity-inlet and the outlet was established as outflow.

3 Results and Discussion

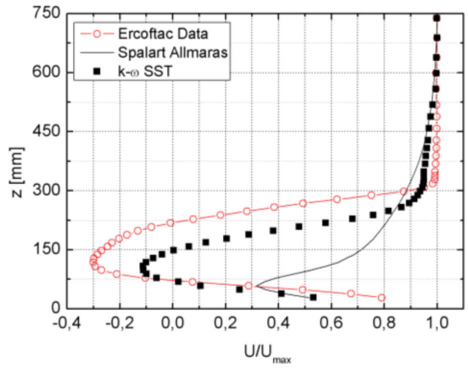
3.1 Ahmed Body

The Ahmed body simulation was performed in steady state with 5000 iterations using the $k-\omega\ SST$ and Spalart-Allmaras turbulence models. The parameters used are slant angle of 35°, kinematic viscosity of $1.5\ \text{x}10^{-5}\text{m}^2/\text{s}$ and flow velocity of 40 m/s, in agreement with experimental data available for comparisons.

The velocity profiles were obtained for different positions. Fig. 8 presents the velocity profiles in a symmetry plane for the 37 and 237 mm locations on the rear of the body. The origin-reference was considered in the rear-end of the Ahmed body.



(a) 37 mm



(b) 237 mm

Fig. 8. Velocity profiles for validation of the numerical technique (Ahmed body) – (a) 37 mm and (b) 237mm.

From Fig. 8, it is possible to note that with the use of k-ω SST model the results were closer to the experimental data. What is interesting to observe is that the near-wake flow at 37 mm behind the body was well captured in the simulation, with values closer to the experimental result when compared with the data obtained from the Spalart-Allmaras model, mainly regarding the prediction of velocity-inflection region. As moving to the flow-recirculation region the k-ω SST turbulence model still presents reasonable data with certain lack of agreement in the amount of momentum-deficit in the 237 mm location.

Fig. 9 presents the velocity magnitude contours for Ahmed body using k-ω SST turbulence model, whose results have been closest to those obtained by Lienhart and Becker (2003) experimentally.

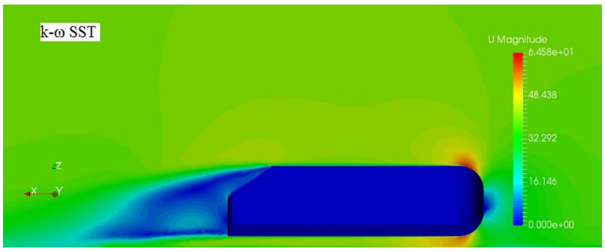
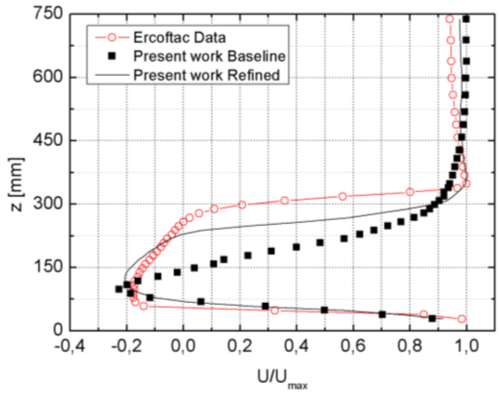


Fig. 9 – Velocity magnitude contours using $k - \omega\ SST$ turbulence model.

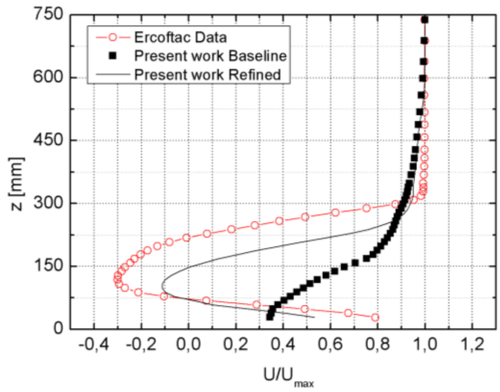
Analyzing Fig. 9, it is observed that the speed magnitude contours calculated using k-ω SST in this work have a satisfactory pattern when compared to that expected for a car geometry, with a stagnation region in the front, acceleration of the flow over the hood or above the windshield and flow separation in the rear of the body resulting in a wake with complex 3D-flow structures behind the body.

To verify the influence of the mesh resolution, the same velocity profiles were taken in the two distinct positions, as presented, being 37 mm and 237 mm behind the body. It is important to remember that the coarser mesh was about 4.8 million elements and the refined one with approximately 17 million elements.

Fig. 10 presents the velocity profiles for baseline and refined meshes. As it is expected the mesh refinement has a great influence in the computational result as has been commented on other works in literature. At the rear end of the Ahmed body the flow is separating and recirculating with strong velocity gradients which needs to be well-captured in the numerical simulation. It is confirmed by these results that the baseline configuration-mesh with almost 5 million points was not able to capture these phenomena. Also, it is important to mention that other work as Nebenfuhr (2010) has commented the dependence of OpenFOAM with the mesh resolution, what could influence the results if no special attention is given to the distribution of the points and quality of the mesh (skewness and aspect ratio) at the end.



(a) 37 mm



(a) 237 mm

Fig. 10. Velocity profiles for baseline and refined meshes – (a) 37 mm and (b) 237 mm.

3.2 Pickup model

As previously seen, the Ahmed body validation was used to select the best turbulence model, in terms of better results when compared with the values obtained experimentally in the literature. Based on the results, the two pickup configurations (baseline and rounded models) were evaluated using the turbulence model k-ω SST which was more consistent with the flow description at the rear end of the body.

Thus, the baseline geometry was evaluated in the OpenFOAM software, whereas the rounded geometry was studied in the Ansys-Fluent® software. At this point, we must clarify that the issue with mesh resolution and quality was clearly perceived in this work, since the mesh for the rounded-pickup could not run in OpenFOAM software, receiving an expected *float-point operation* and divergence under several trials with modeling setup. The same mesh was exported to Ansys-Fluent ® and processed without error-messages and reaching convergence at approximately 2000 iterations. This issue with the mesh for the rounded-pickup configuration is still under analysis.

The quantitative (velocity profiles) and qualitative data (contours) have been assessed and compared with the data from Silva-Pinto (2016) and Almeida (2017).

Fig. 11 shows the velocity profile for the baseline model at the P1 (78 mm in front of the body), P2 (50 mm from the back of the body) and P3 (92.57 mm from the back of the body) positions, respectively, compared with the experimental and numerical values by Almeida (2017), considering the velocity of 25m/s.

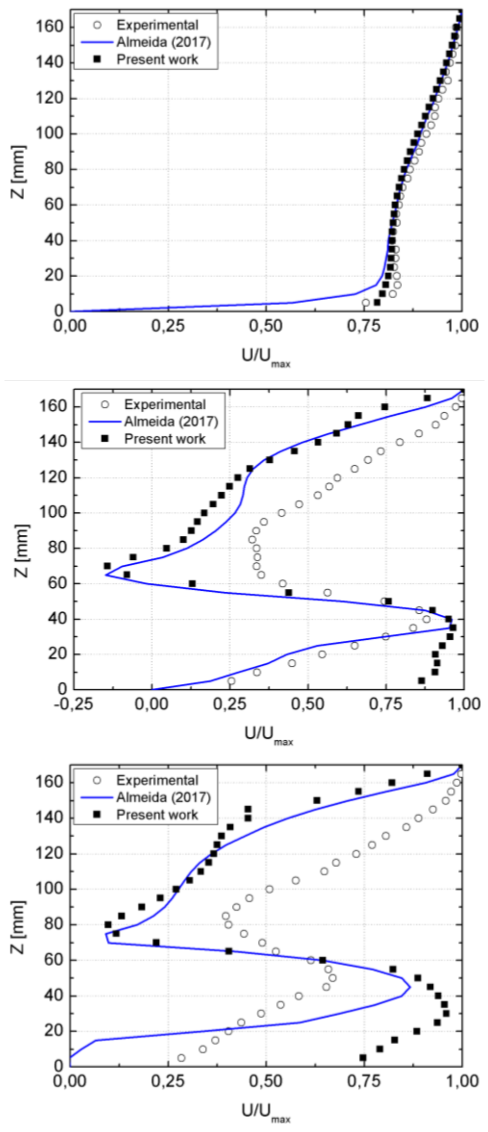


Fig. 11. Numerical and experimental velocity profiles for $U_0 = 25\ m/s$ – baseline pickup.

Fig. 11 shows that the computational result of the present work obtained a good approximation of the values obtained by Almeida (2017), with a difficulty in defining the profile close to the body wall, which can be justified by the absence of the layer of prisms in the mesh used. At this time, it was avoided to stretch the mesh, keeping it more uniform around the model, to make it possible to run in OpenFOAM.

In addition, the values for the drag coefficient of both models were obtained and compared with the numerical results, in the software STAR-CCM+ of Silva-Pinto (2016). These results are presented in Table 1.

Table 1. Drag coefficients comparison.

	Baseline	**Rounded**
C_D present work	0.5396	0.4310
C_D ***Silva – Pinto*** **(2016)**	0.5376	0.3607

From the results obtained for the baseline and rounded models in this work, a variation of the drag coefficient around $\Delta C_D = 0.11$ was observed, that is a reduction of approximately 20%.

The difference obtained between the variation of the drag coefficient between the present work and that obtained by Silva-Pinto (2016) can be justified using the Fluent® software in the analysis of the rounded configuration. Issues with the mesh resolution will be addressed and presented in future works, as this is an ongoing research for evaluation of experimental and numerical tools for aerodynamic prediction of pickup-trucks.

Furthermore, the velocity contours in the plane of symmetry for the two pickups were evaluated at a velocity of 25 m/s. Fig. 12 shows the comparison between the velocity fields for both baseline and rounded pickup models. Flow separation at the front hood is evident for the baseline configuration (flat surfaces). Also, the stagnation point region is bigger in the baseline configuration when compared to the rounded pickup. These local changes in the flow field is contributing to a very different flow pattern in the trunk (behind cabin) and near-wake region. The flow underneath is almost similar.

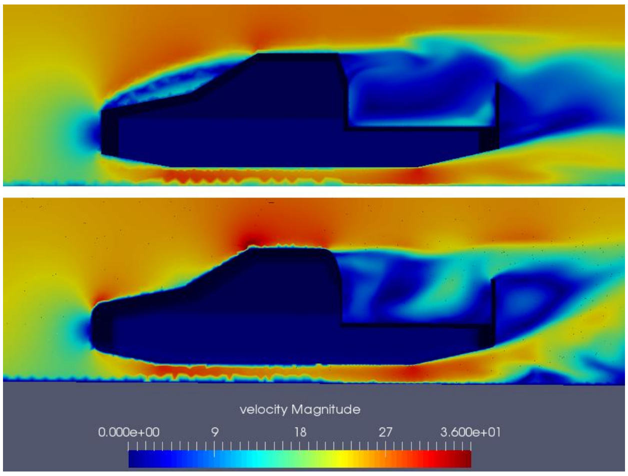


Fig. 12. Velocity field on symmetry plane for baseline model (top) and for rounded model (bottom).

To improve the comparisons, Fig. 13 and Fig. 14 show the turbulent structures (recirculation region) formed at the trunk (behind cabin) for the baseline and rounded models, respectively, and their comparisons with results from literature.

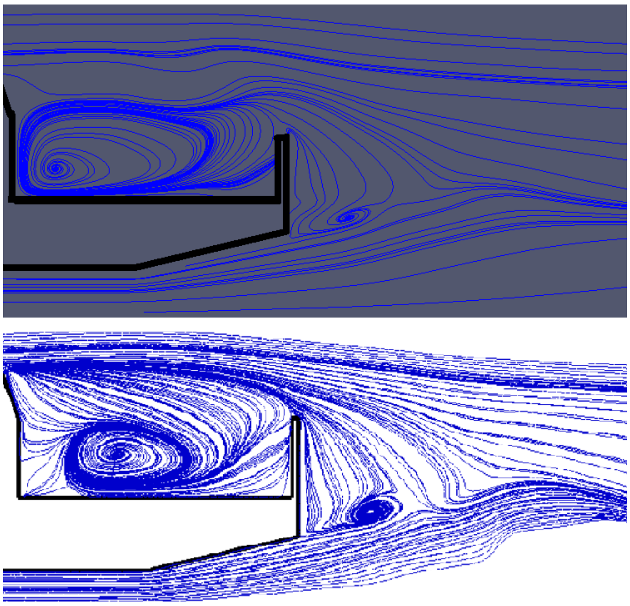


Fig. 13. Turbulent structures formed at the trunk from this work (top) and from Silva-Pinto (2016) (bottom) for baseline pickup.

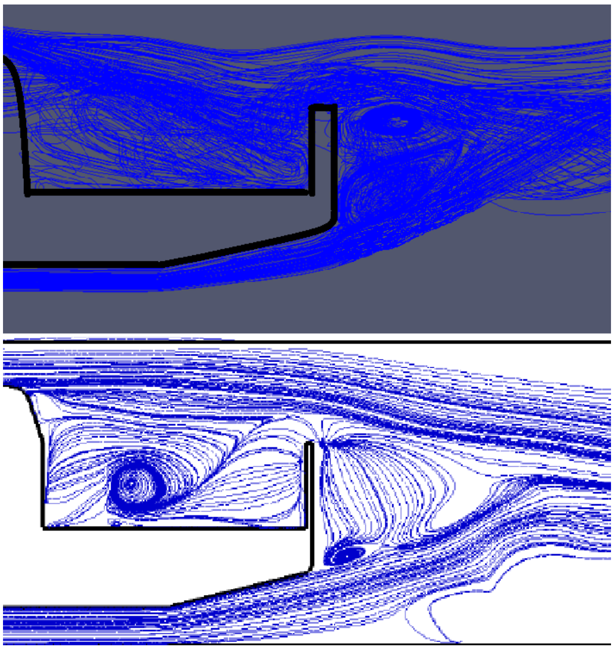


Fig. 14. Turbulence structures formed at the rear from this work (top) and from Almeida (2017) (bottom) for rounded model.

From Figs. 13 and 14, the approximation between the results obtained in this work and those presented in Silva-Pinto (2016) is observed. As it could be identified, the prediction of the turbulent structures for the rounded pickup, by using the Fluent® software, generated two counter-rotating bubbles in the rear of the vehicle, unlike that obtained by Silva-Pinto (2017). This was an important finding in this work and as mentioned before, the flow structure's prediction has some influence for the meshing process, which must be closely analyzed in the sequence of this work. As seen in Fig. 13, for the baseline pickup, the results were more similar. It is believed that the imposition of the separation points, due to the flat surfaces, has contributed to a better physical description of the flow by the k-ω SST turbulence modeling, whereas the boundary layer separation over smoothed surfaces were more challenging for the numerical approach used herein. This has been another aspect that is being addressed in the continuation of this research.

Finally, it is important to emphasize that the flow over a pickup truck is not simple and deserves attention in the process of modeling. As described herein some important issues have been revealed.

4 Conclusions

This work presented a computational RANS (Reynolds-averaged Navier-Stokes) approach with two different turbulence modeling for solving the problem of the flow around commercial vehicles such as pickup trucks. The flow field solution has been obtained with the use of an open-source code OpenFOAM, which is the reference platform for developing further vehicle aerodynamic's optimization research which is going on at the Experimental Aerodynamics Research Center – CPAERO in the Federal University of Uberlândia (UFU) / Brazil.

The information obtained about the mesh refinement influence in OpenFOAM simulations was proven in the present work. In addition, the results obtained for the Ahmed body when compared with the reference experimental values showed good approximation, mainly with the use of the k–ω SST turbulence model.

Regarding the pickup truck, there was a significant reduction of the drag coefficient from the smoothing of the model, reaching approximately 20% reduction of this parameter. Issues with mesh resolution and quality were proven to be an important step of further work with OpenFOAM and guidelines should be addressed in near term future.

Thus, the results of the studies carried out in this study were satisfactory for the understanding and fulfillment of the proposed topics.

References

[1] AHMED, S. R., RAMM, G. and FALTIN, G., "Some salient features of the time-averaged ground vehicle wake", SAE Special Publication,1984, 569, 1–31.

[2] HUCHO, W-H., "Aerodynamics of Road Vehicles", SAE International, 1998, ISBN: 0-7680-0029-7.

[3] ISMAIL, K. A. R., "Aerodinâmica Veicular", 2007, Gráfica Cisgraf, ISBN 85-900609-6- 9.

[4] KATZ, J., "Race Car Aerodymics: Designing for Speed (Engineering and Performance), Bentley Publishers", 1995, ISBN-13: 978-0837601427.

[5] GILLESPIEL, T., "Fundamental of Vehicle Dynamics, SAE International", 1992, ISBN-13: 978-1560911999.

[6] LIENHART, H., STOOTS, C. and BECKER, S., "Flow and turbulence structures in the wake of a simplified car model (Ahmed model)", Notes on Numerical Fluid Mechanics, 2002, 77, 323-330.

[7] HEFT, A. I., INDINGER, T. and ADAMS, N. "Introduction of a new realistic generic car model for aerodynamic investigations.", SAE International, 2012, Paper number: 900316.

[8] WILCOX, D. C., "Formulation of the k–ω Turbulence Model Revisited", 46 (11), AIAA Journal, 2008, pp. 2823–
2838, Bibcode:2008AIAAJ..46.2823W, doi:10.2514/
1.36541.

[9] MENTER, F. R., "Zonal Two Equation k-ω Turbulence Models for Aerodynamic Flows", AIAA, 1993, Paper 93-2906.

[10] MENTER, F. R., "Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications", AIAA Journal, 1994, vol. 32, no 8. pp. 1598-1605.

[11] ERCOFTAC, "Flow around a simplified car body (Ahmed body)" , (2002), Available from <http://www.ercoftac.org/_leadmin/user upload/big_les/sig15/database/9.4/ws_10.html.> Accessed on July 06, 2017.

[12] WOJCIAK, J., ADAMS, N.,INDINGER, T., THEISSEN, P. ,DEMUTH, R., "Investigation of Unsteady Vehicle Aerodynamics under Time-Dependent Flow conditions", 29th AIAA Applied Aerodynamics Conference, June 27-30, 2011, Honolulu, Hawaii, USA, Paper AIAA 2011-3349.

[13] ALMEIDA, O., PINTO, W.J.G.S., ROSA, S.C., "Experimental Analysis of the Flow Over a Commercial Vehicle - Pickup", International Review of Mechanical Engineering (I.R.E.M.E), Vol.11, nº8, 2017, pp. 530–537.

[14] NEBENFÜHR, B., "OpenFOAM: A tool for predicting automotive relevant folw", 2010. 144 f. Master's Thesis in Automotive Engineering, Department Of Applied Mechanics, Chalmers University Of Technology, Göteborg, Sweden, 2010.

[15] LEWIS, R., MOSEDALE, A., ANNETTS, I., "Using OpenFOAM and ANSA for Road and Race Car CFD. Halkidiki, Greece. 3rd Ansa & μeta International Conference, 2009. 17 p.

[16] HUCHO, W. H., "Aerodynamics of Road Vehicles, 4th Edition, SAE International, 1998.

[17] BORDEI, Ş., POPESCU, F., "Aerodynamic Results for a Notchback Race Car", Fascicle V, Technologies In Machine Building, 2011.

[18] AL-GARNI, A. M., BERNAL, L. P., "Experimental study of a pickup truck near wake. Journal of Wind Engineering and Industrial Aerodynamics", p. 100-112, 2010.

[19] PINTO, W. J. G. S. P., "Numerical and Experimental Analysis of the Flow Over A Commercial Vehicle – Pickup", 95 p. Undergraduation Conclusion Work (TCC) in Mechanical Engineering, Federal University of Uberlândia, Uberlândia, 2016.

5 Contact Author Email Address

Eduarda Mascia - mailto:eduardamascia@ufu.br

Odenir de Almeida - mailto:odenir.almeida@ufu.br

Copyright Statement